MSM OE Mixing Detectors and CDMA Readout for Imaging CoHerent Optical Radar (ICHOR)

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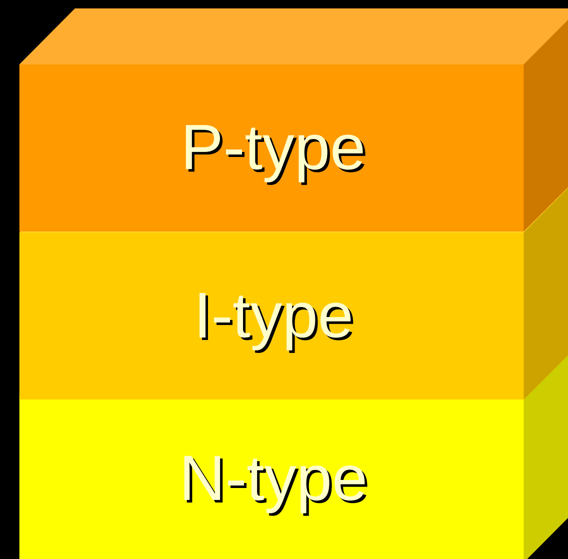
05 Dec 2003

Outline

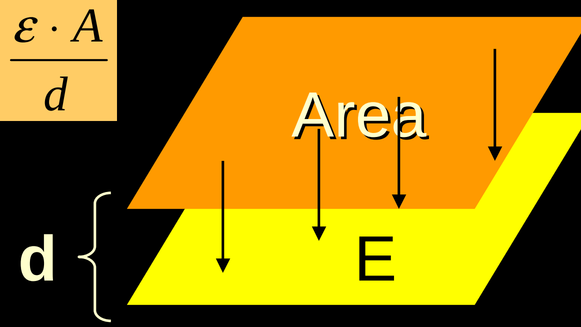
- Overview
  - PIN Detectors and MSM Detectors
  - Opto-Electronic (OE) Mixing with MSM Detectors
  - InGaAs MSM Detectors Development at ARL
- Application of MSM Detectors to ICHOR
  - Frequency Down-Conversion
  - Frequency Tracking
- CDMA for High Speed FPA Readout
  - Code Multiplexing via OE Mixing
  - Code Multiplexing via ROIC
- Conclusions

PIN Detector

- Reverse biased
- Rectified I-V
- Intrinsic region absorbs most of the photons
- Larger capacitance per unit area than MSM (two parallel plates model)
  - 25fF capacitance for 20μm spot size detector

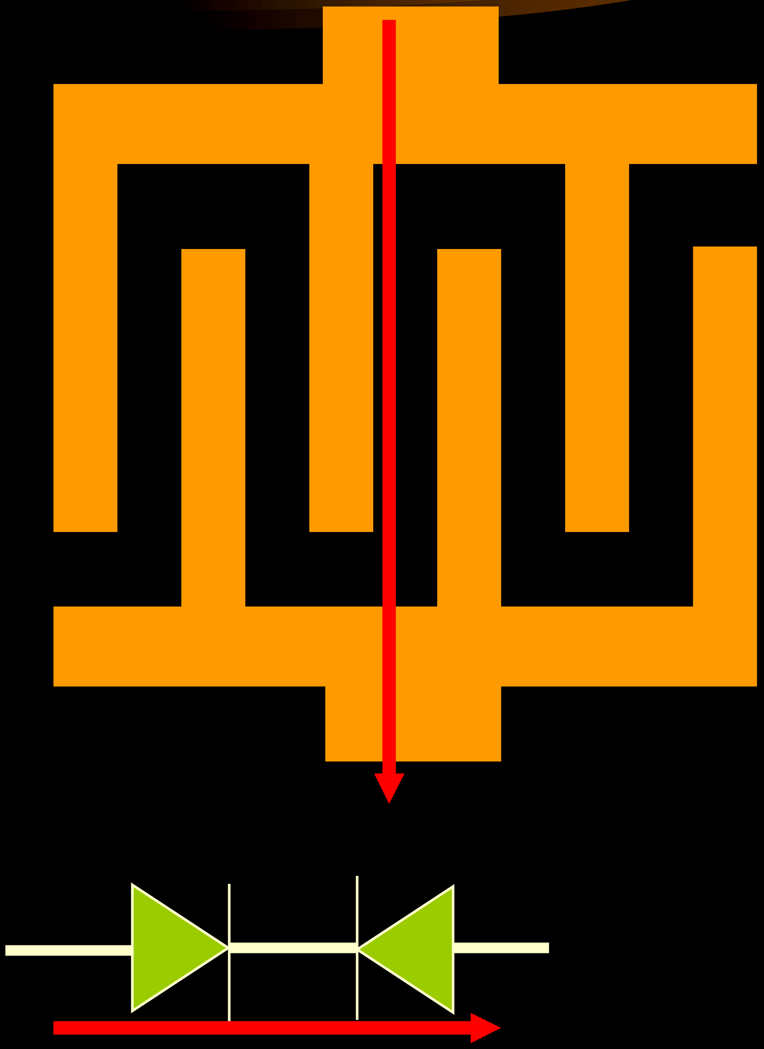


$$C = \frac{\varepsilon \cdot A}{d}$$

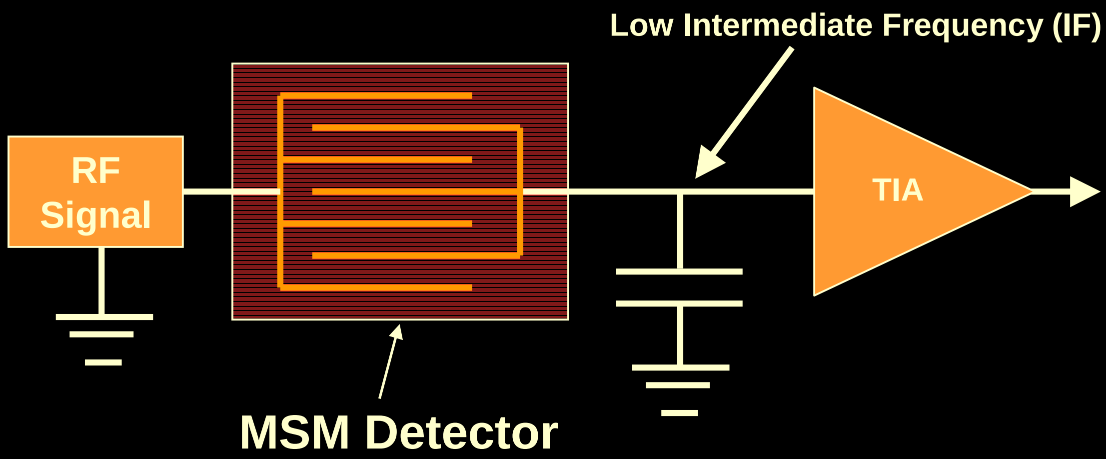


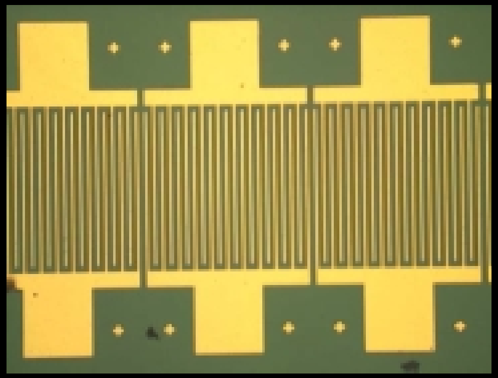
MSM Detector

- MSM photodiodes are comprised of back-to-back Schottky diodes formed by an interdigitated electrode configuration on top of an active light collection region.
- Bipolarity Enables Balanced Mixing
- Smaller capacitance per unit area than PIN
  - 10fF capacitance for 20μm spot size detector
- Planarity

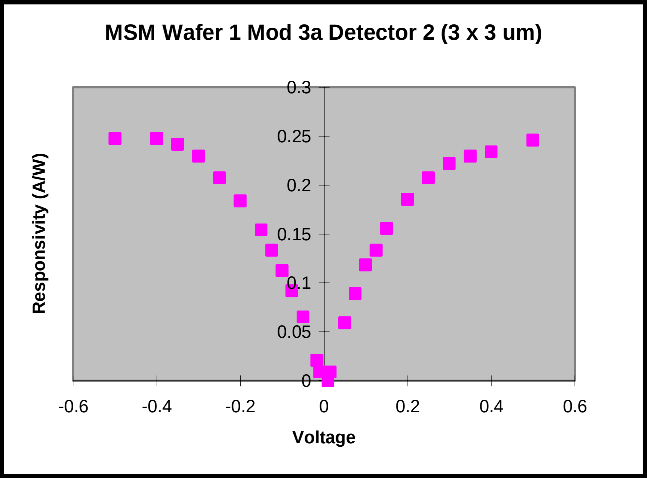


MSM Detectors for Opto-Electronic (OE) Mixing



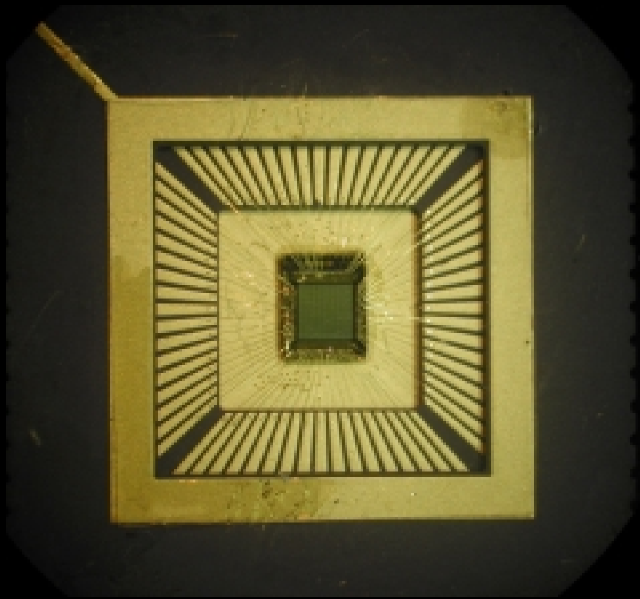


- Invented at ARL (Patent in Process) and in development at ARL and BAE
- Provides Balanced Mixing
- Good Responsivity and Low Noise for GaAs Devices at 0.8 μm
  - Demonstrated 32 x 32 array
- Good Responsivity and Low Noise for single InGaAs Devices for 1.5 μm
  - Developing arrays



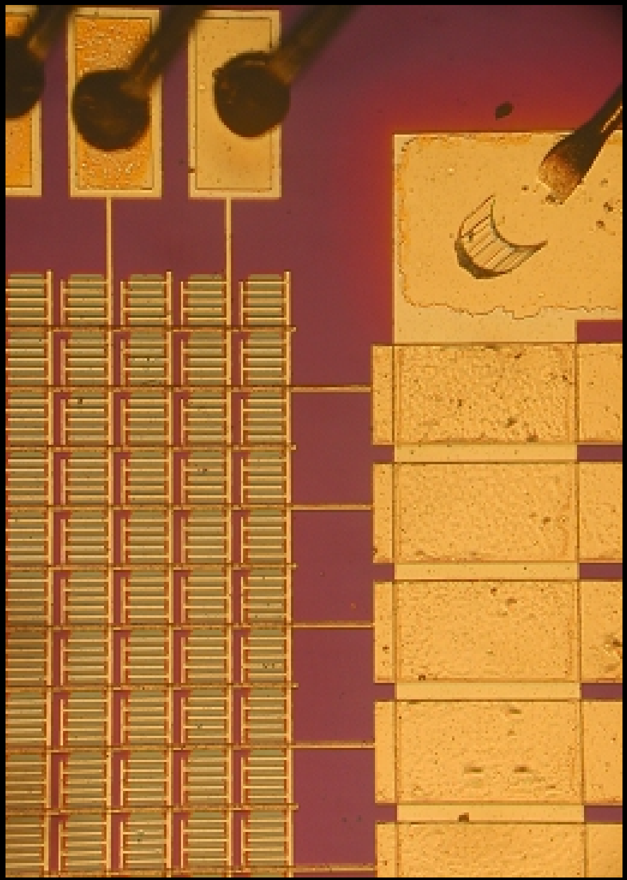
Responsivity vs LO voltage

32 x 32 Pixel GaAs MSM Detector Array



32 x 32 Pixel GaAs MSM Array in Carrier

- 60 x 60 µm Pixel
- Includes On-chip RF Bypass Capacitors

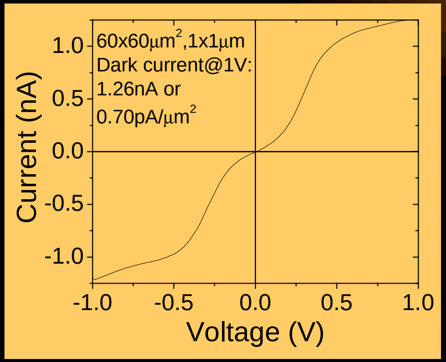


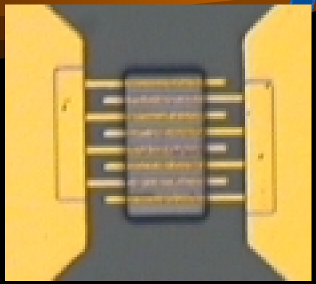
Portion of 32 x 32 Pixel Array

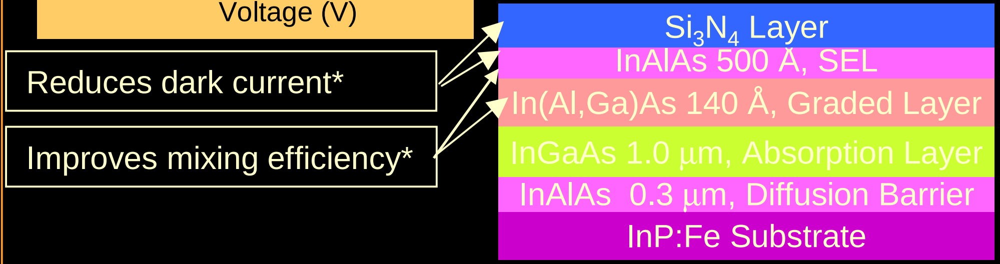
OE Mixing InGaAs MSM Detector for Ladar

Goals:

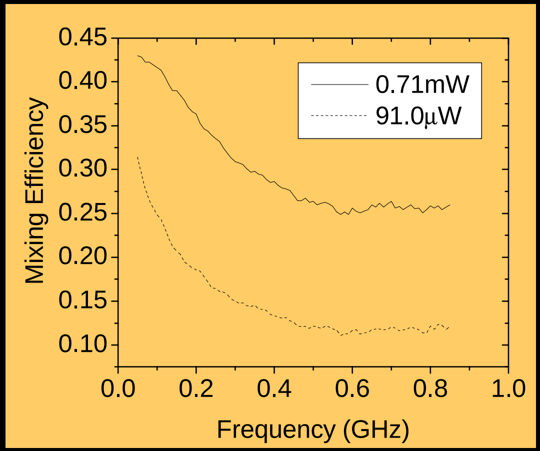
- Develop high-speed, 1.5μm sensitive InGaAs MSM OE Mixing FPAs
- Increase SNR ⇒ Reduce dark current of InGaAs MSM detectors
- Increase mixing efficiency







Mixing efficiency:

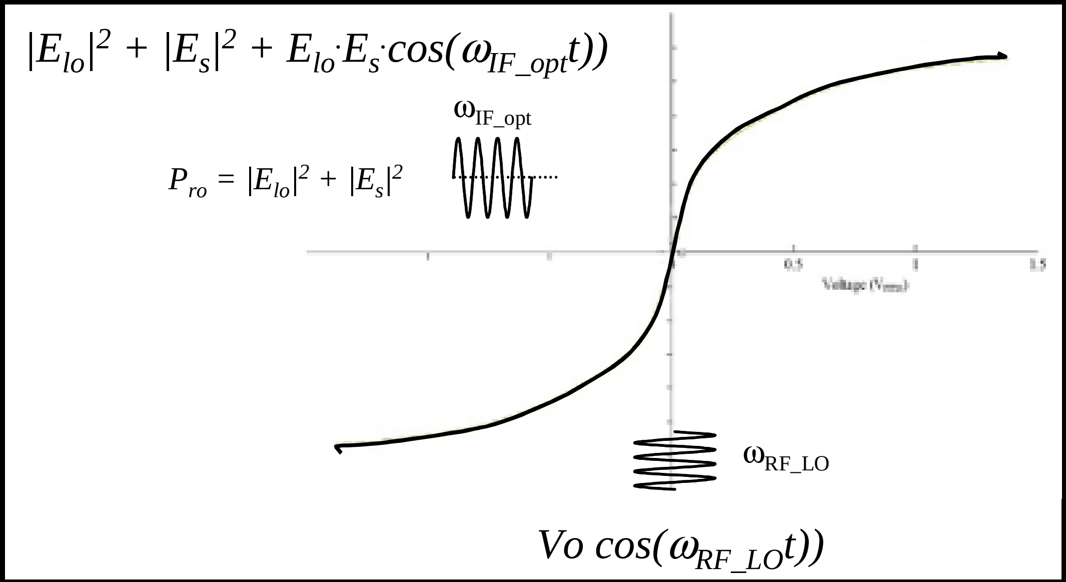


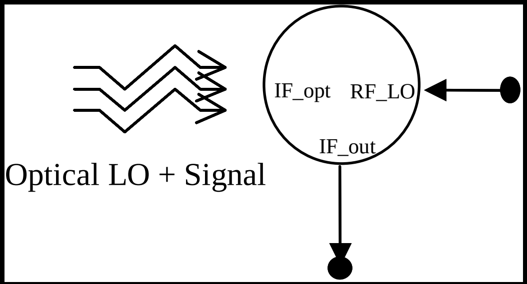
Accomplishments:

- **Developed a 1.5μm MSM OE Mixing detector for ARL Ladar applications**
- **Reduced dark current 6 orders-of-magnitude (<2nA@1V)***
- **Demonstrated mixing in InGaAs detector (Mixing Efficiency >25% @ 0.8GHz)***
- **Developing FPAs with BAE**

Aliberti, K., et. al., "Improved optoelectronic mixing of InAlAs/InGaAs interdigitated-finger metal-semiconductor-metal photodetectors," Proc. IEEE Sensors 2003, held Oct. 2003, yet to be published.

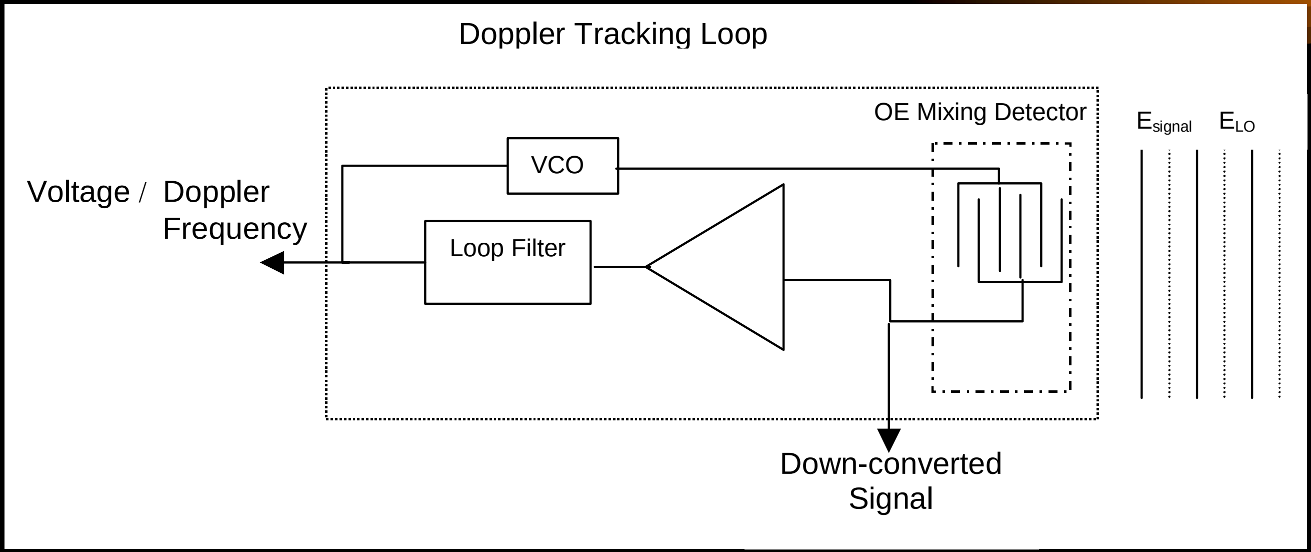
OE Mixing for Frequency Down-conversion





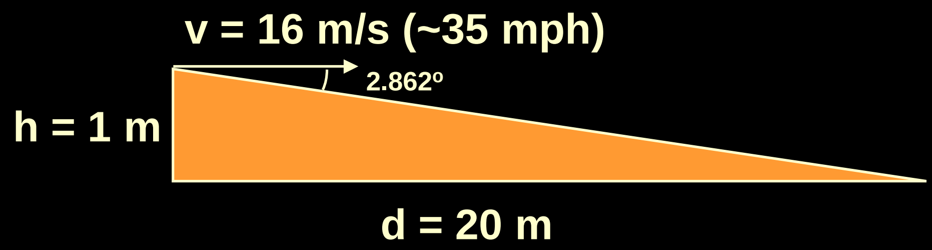
- Down-convert high frequency signals through the OE mixing process to a lower frequency signal
  - Reduce amplifier bandwidth & digitizer sampling rates
  - Enables tracking of Doppler frequency of moving targets at the FPA
  - Can be used for phase encoding for code-multiplexing readout
- Operate detector bias with zero mean so “mixing” is balanced
  - Average responsivity is zero => No DC term

Doppler Tracking using OE Mixing



- **Enables Doppler Tracking at the FPA**
  - **Down-conversion to lower IF => Lower ROIC Bandwidth and Digitizer Sampling Rate**
  - **Fewer Components than using post-detector RF mixer enables on-chip integration for "Smart Focal Plane Array"**
- **Doppler tracking in the electronic domain is easier to implement for an array compared to Doppler tracking via multiple optical LOs**

Doppler Shift Example for Buried Mine Detection



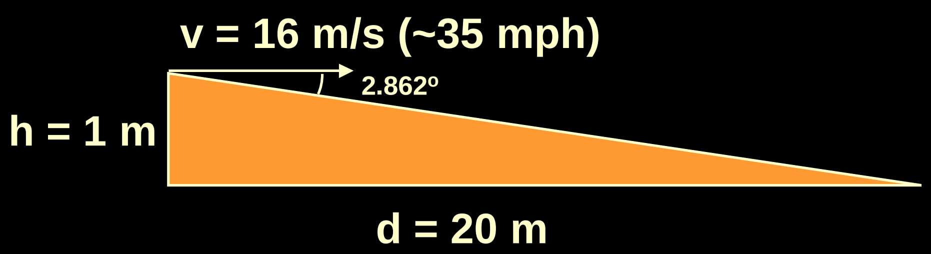
$$f_{doppler} = 2 \cdot \frac{v}{\lambda} \cdot \cos\left(\operatorname{atan}\left(\frac{h}{d}\right)\right)$$

$f_{doppler}$ = 20.62 MHz for λ = 1.55 μm

- If the highest vibration frequency of interest is ~1kHz, for the diagrammed scenario above, 0.1s dwell, and 32x32 array, the system needs
  - ~21 MHz amplifier bandwidth on-chip => ~42 Msps sampling rate
    - =>a buffer of 4.2 million samples per pixel per dwell => 134 million samples per row per dwell
    - For time multiplexing with individual row readouts, the ROIC needs to run at 1.34 Gsps to clock out the data in 1 dwell time,

    OR
  - A bank of ~11,000 bandpass filters per pixel on-chip, each of ~2 kHz bandwidth, for an amplifier bandwidth of ~2 kHz
    - 11,000 threshold detectors (comparators) per pixel and digitize the outputs of the possibly 2 filters that are above threshold
    - For 32 pixels per row and time multiplexing with individual row readouts, the ROIC needs to run at 256 Ksps to clock out the data in 1 dwell time, OR

Doppler Shift Example for Buried Mine Detection



$$f_{doppler} = 2 \cdot \frac{v}{\lambda} \cdot \cos\left(\operatorname{atan}\left(\frac{h}{d}\right)\right)$$

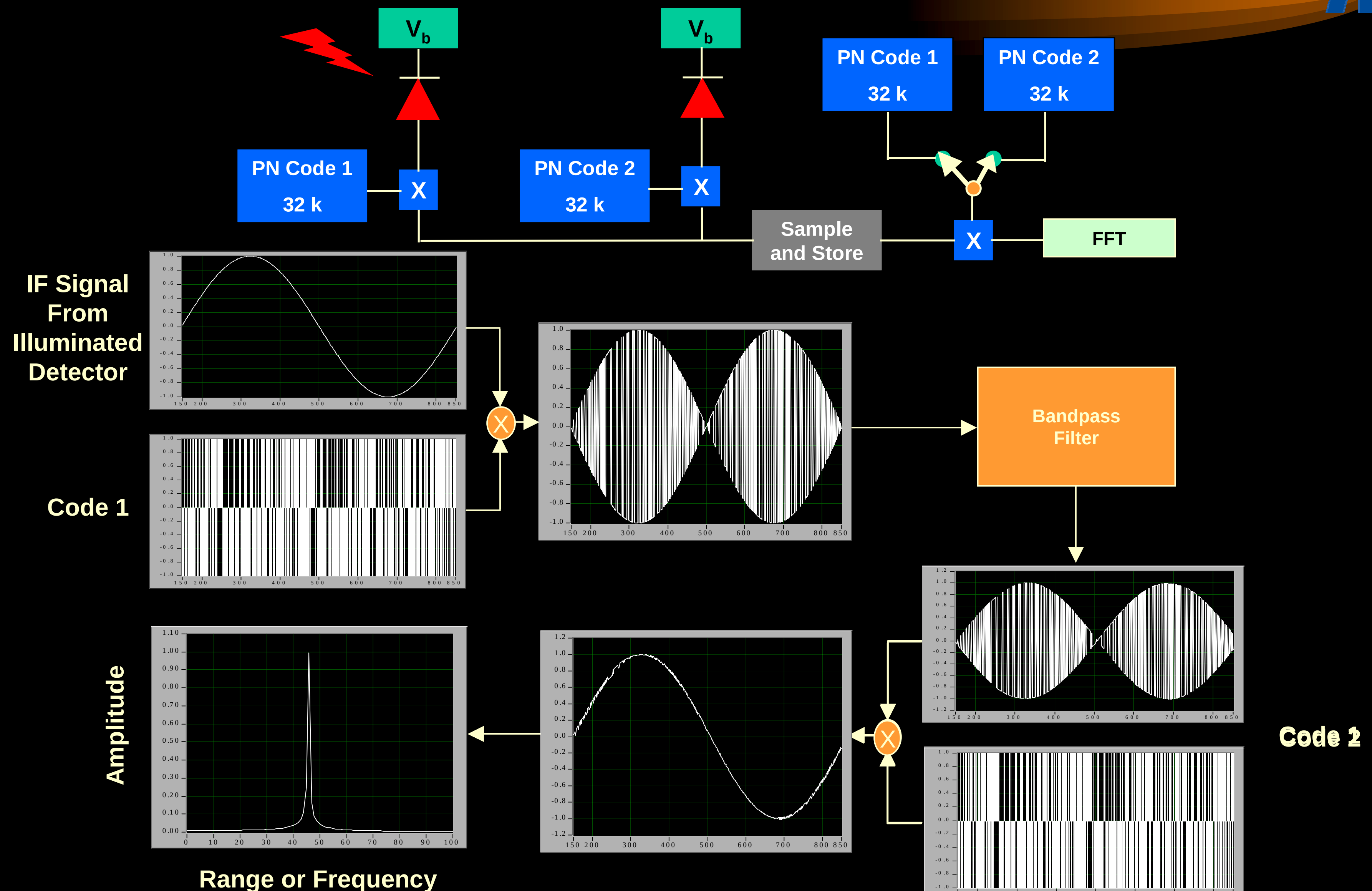
$f_{doppler}$ = 20.62 MHz for λ = 1.55 μm

- A Doppler tracking loop with an amplifier bandwidth of ~1 kHz
  - Implement with MSM detectors for a Doppler tracking smart FPA
  - => a buffer depth of ~200 samples per dwell per pixel
    => 6,400 samples per dwell per row
  - For 32 pixels per row and time multiplexing with individual row readouts, the ROIC needs to run at 64 Ksps to clock out the data within 1 dwell time,

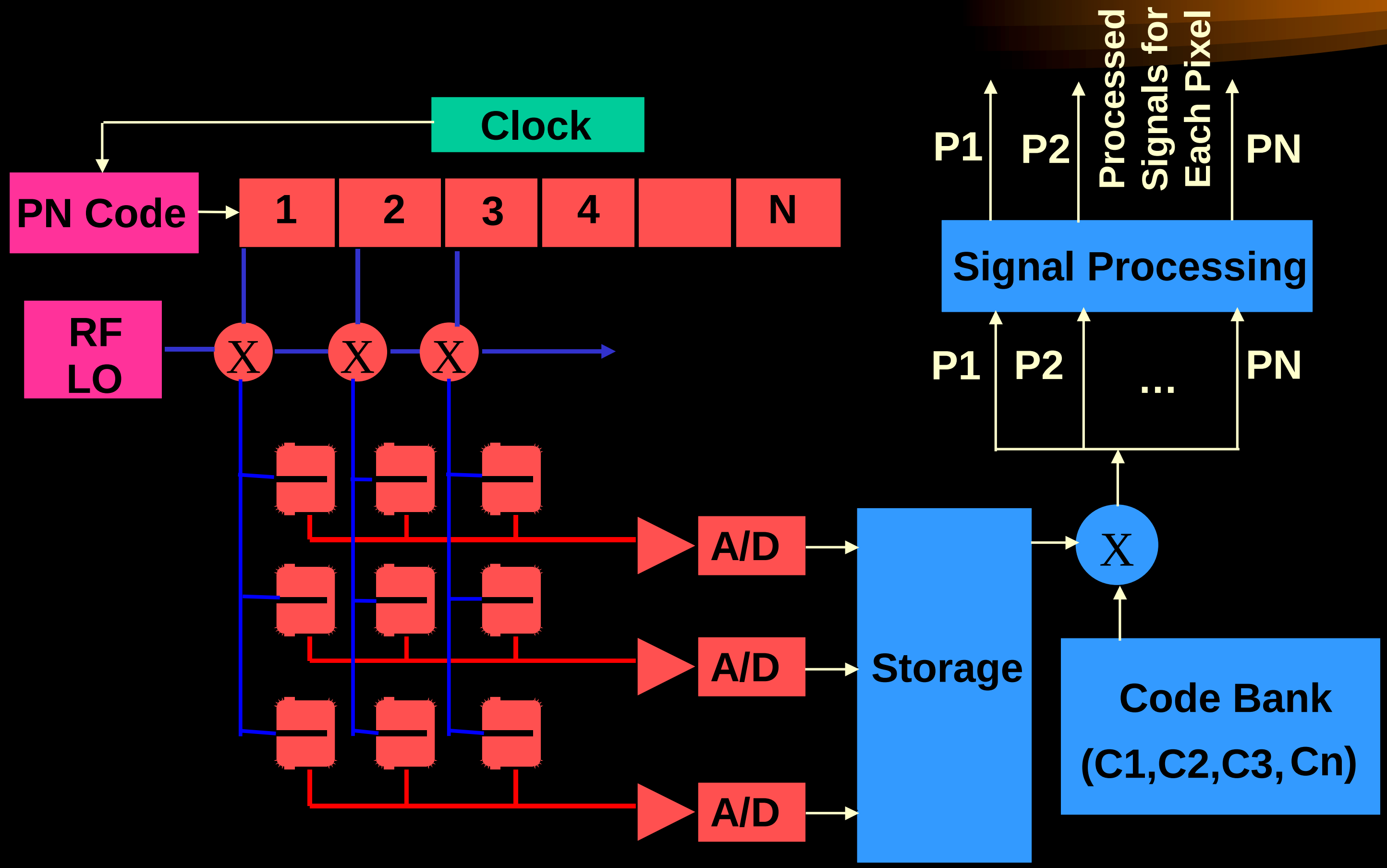
OR

- Code multiplexing and ~21 MHz amplifier bandwidth
  - Using code multiplexing with individual row readouts with a code rate of 327.7 Kchips/s, the ROIC needs to clock out the data at 42 Msps
  - =>a buffer depth of 4.2 million samples per dwell per row
  - Implement the Code Demux, Doppler tracking loop, and filter digitally

Code Division Multiple Access (CDMA) Concept for Code-Multiplexing Readout

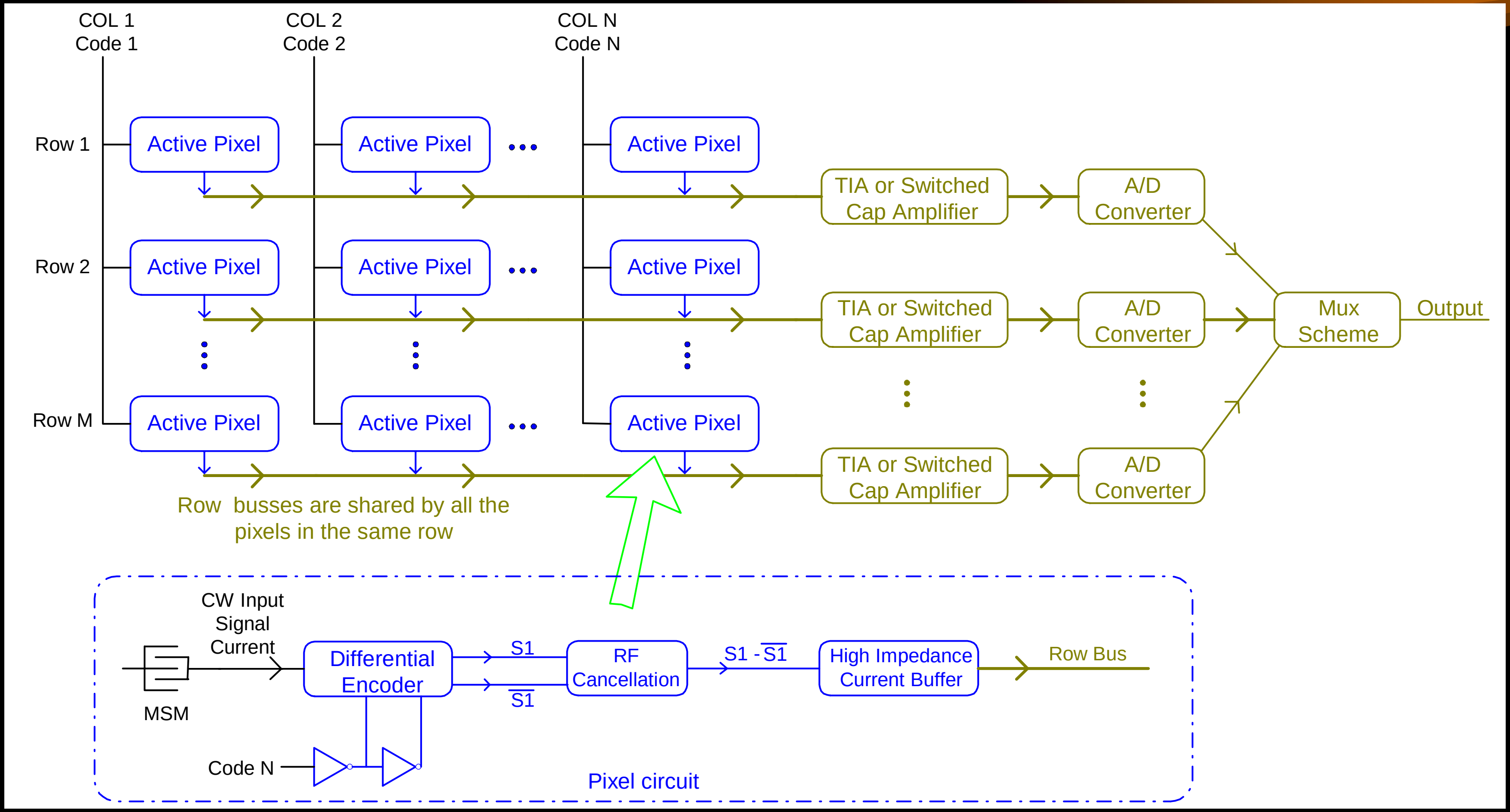


CDMA Readout with Encoding via OE Mixing



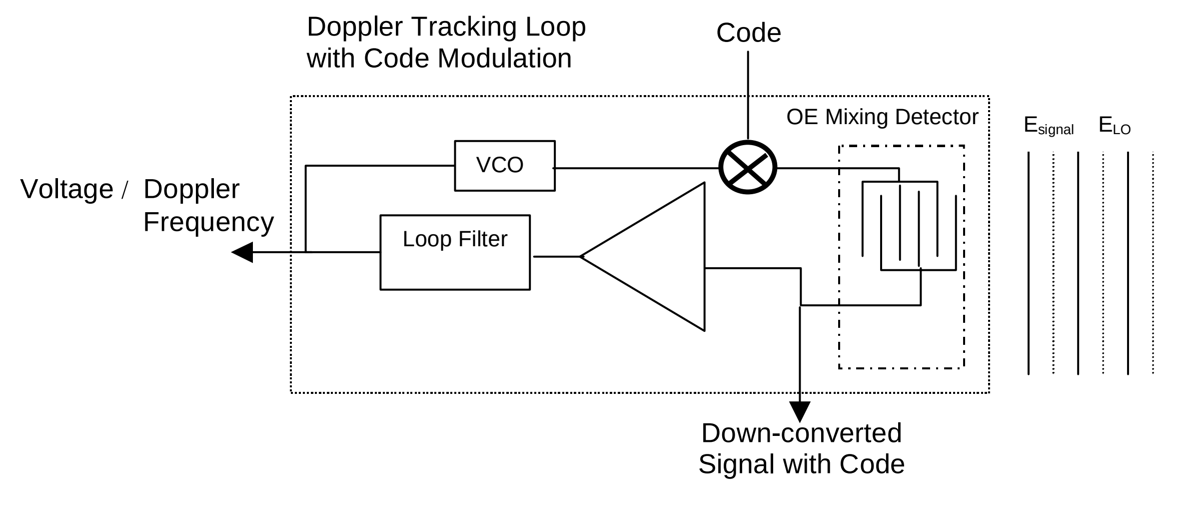
- Reduces required ROIC Readout and Digitizer sampling rates
- CDMA Read-out Requires N Code Lines + N Readout Lines
  - => 2 N Lines for an NxN FPA vs. N^2 as used in other Wideband Ladar FPA ROICs
- Demonstrated in ARL's Chirped AM Ladar Breadboard

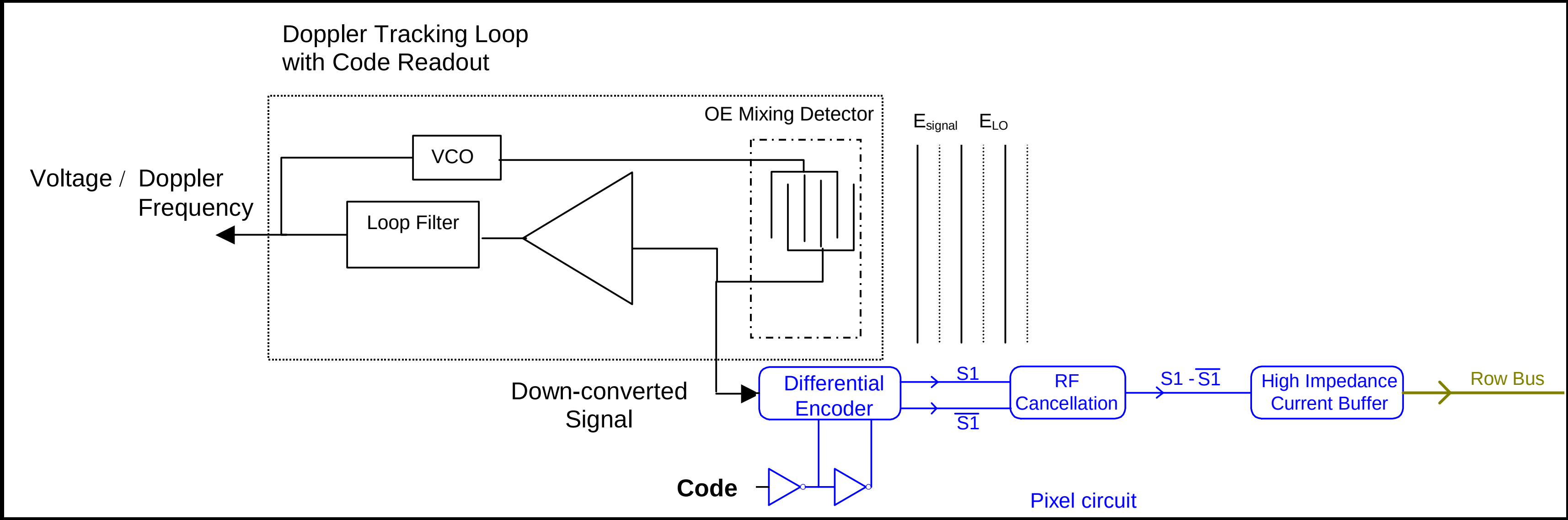
Post-Mixing Encoding for CDMA ROIC



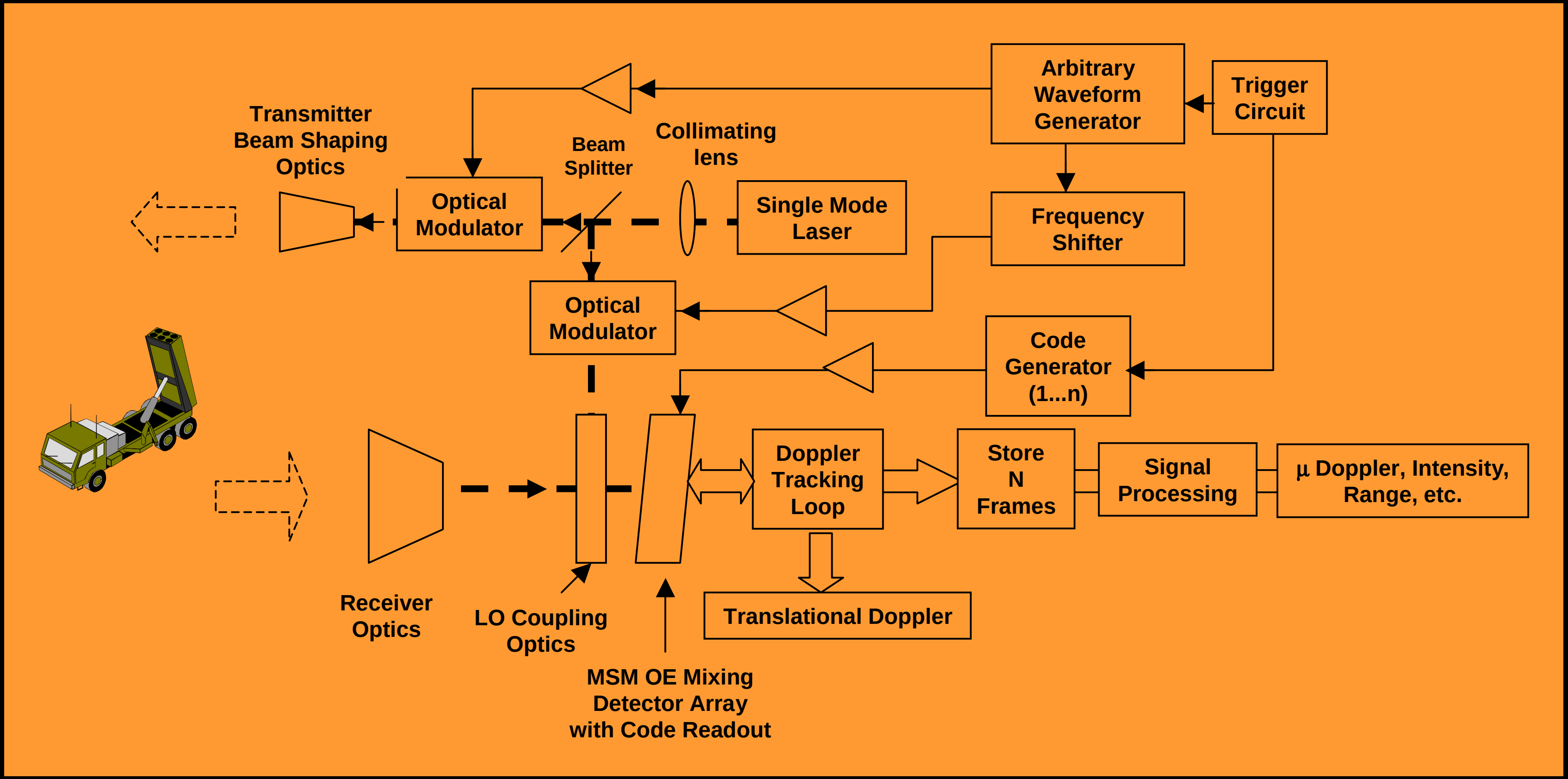
- Reduces required ROIC readout and Digitizer sampling rates
- One RF LO fed to all pixels eliminates RF cross-talk issue compared to Encoding via OE Mixing
- Being developed in a joint ARL and University of Delaware project

Doppler Tracking Loop with Coding





ICHOR using MSM OE Mixing Detectors Conceptual Block Diagram



Conclusion

- **MSM OE Mixing Detectors**
  - Efficient, low dark noise, InGaAs MSM detectors for 1.5 μm regime have been developed at ARL
    - InGaAs MSM FPAs being developed jointly by ARL and BAE leveraging work that led to successful fabrication of GaAs MSM FPAs currently used in the ARL Chirped AM Ladar
  - Provide high frequency RF mixing in the detector for frequency down-conversion and Doppler tracking
    - Reduces ROIC Clock Rate and Digitizer Sampling Rate and Storage
    - Enables Smart FPA Doppler Tracking
  - OE Mixing can be used in implementing Code Multiplexing
- **Code Multiplexing**
  - Code Division Multiple Access (CDMA) Readout invented and demonstrated by ARL for chirped AM ladar
  - Reduces ROIC Clock Rate and Digitizer Sampling Rate
  - Can be implemented with MSM OE Mixing Detectors or in the Post-mixing ROIC
    - Post-mixing ROIC being developed jointly by ARL and University of Delaware
- **Without an On-chip Doppler Tracking Loop or CDMA Readout, Coherent Arrays require ~Gsps ROICs and Digitizers**
  - CDMA Readout can reduce these rates to < 50 Msps
  - Doppler Tracking Loop can reduce these rates to <100 Ksps